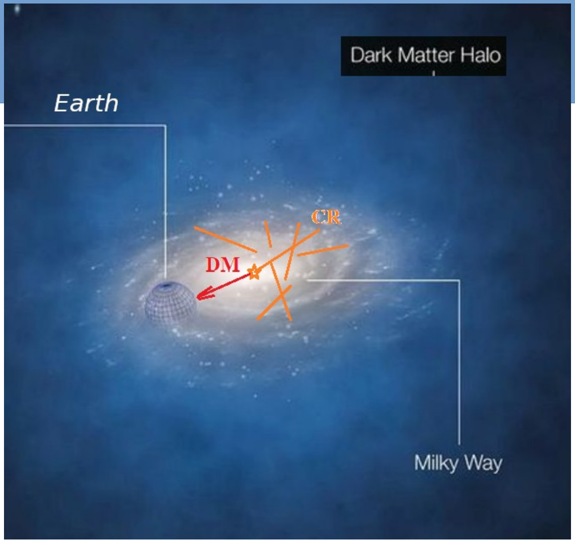
TWENTY-FIRST LOMONOSOV CONFERENCE ON ELEMENTARY PARTICLE PHYSICS

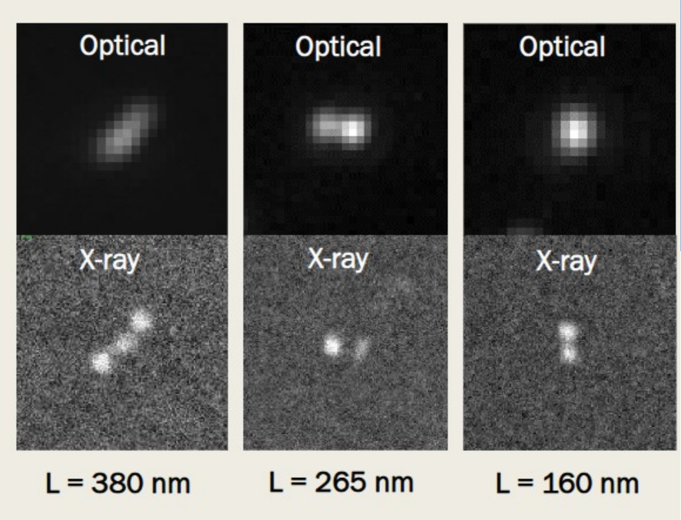


«NEWSdm experiment to search for the cosmic ray boosted Dark Matter»

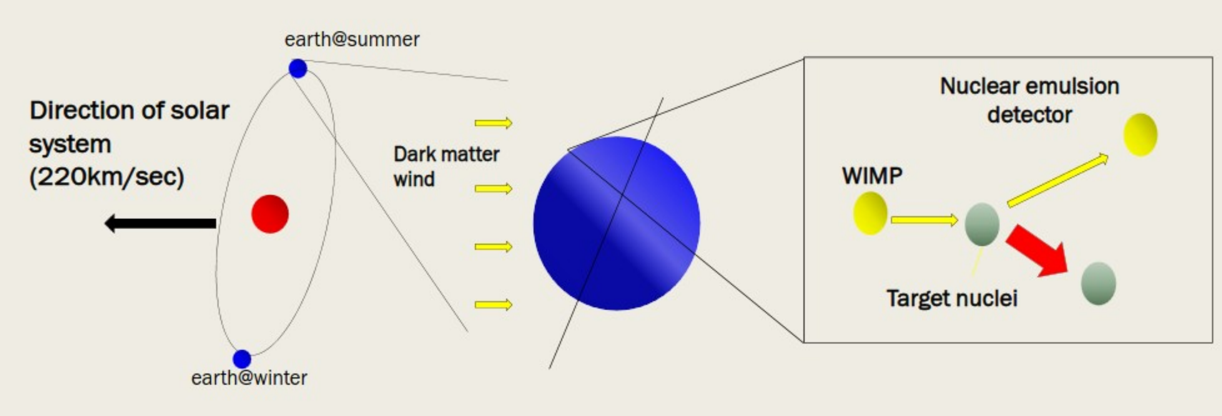
A.M.Anokhina, MSU
on behalf of the NEWSdm collaboration

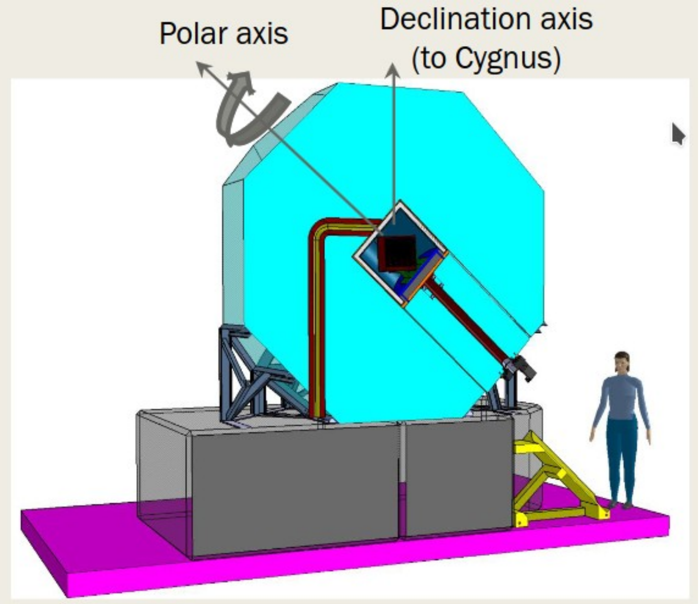
25-08-2023

NEWSdm (Nuclear Emulsion for WIMP Search with a directional measurement), Gran Sasso, Italy.
DARK MATTER DIRECT DETECTION experiment.



Goal: detecting the direction of nuclear recoil from WIMP elastic scattering
Target: nanometric emulsion films (20-40 nm grains) acting both as a target and a tracking detector





Website: http://news-dm.lngs.infn.it/

Letter of intent: https://arxiv.org/pdf/1604.04199.pdf

Dark Matter (WIMP), SUSY extensions of SM
Direct Detection Experiments

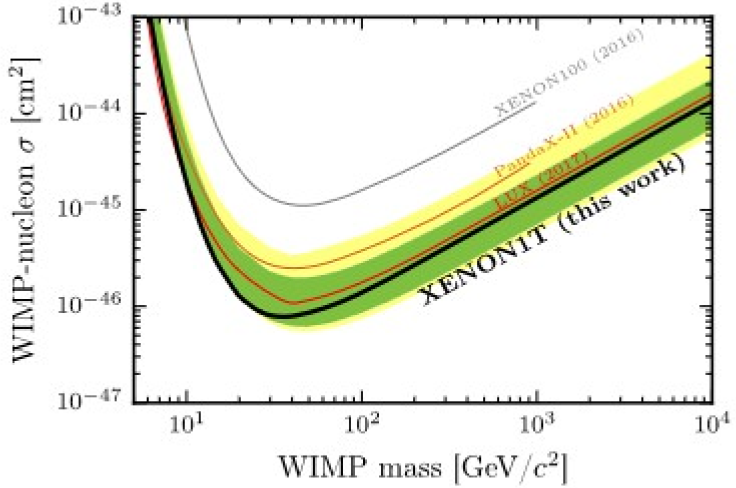


FIG. 4. The spin-independent WIMP-nucleon cross section limits as a function of the WIMP mass at 90% confidence level (black line) for this run of XENON1T. In green and yellow are the 1σ and 2σ sensitivity bands. Results from LUX [27] (the red line), PandaX-II [28] (the brown line), and XENON100 [23] (the gray line) are shown for reference.

PRL 119, 181301 (2017)

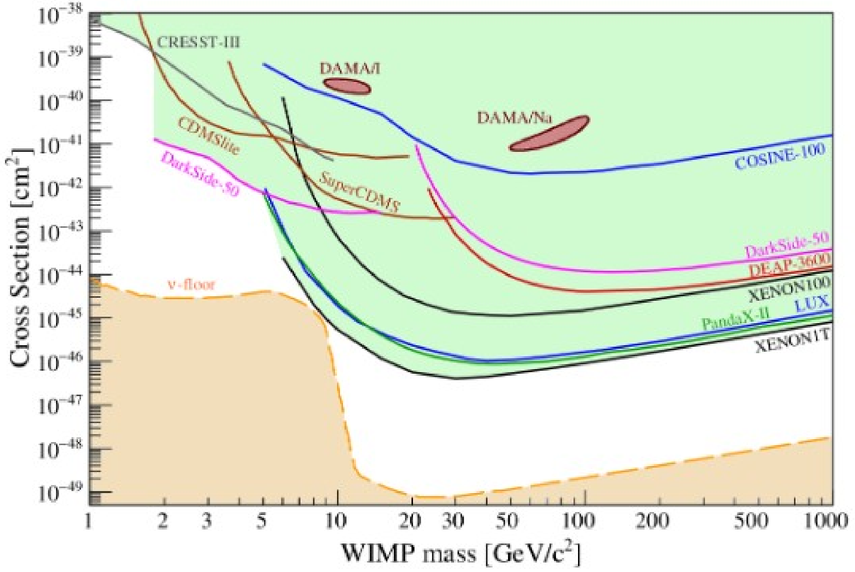
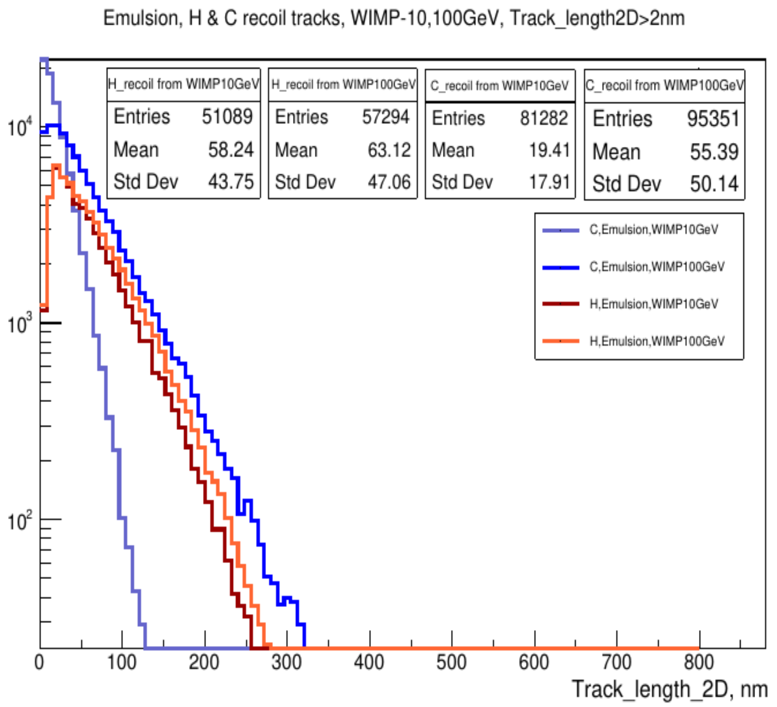
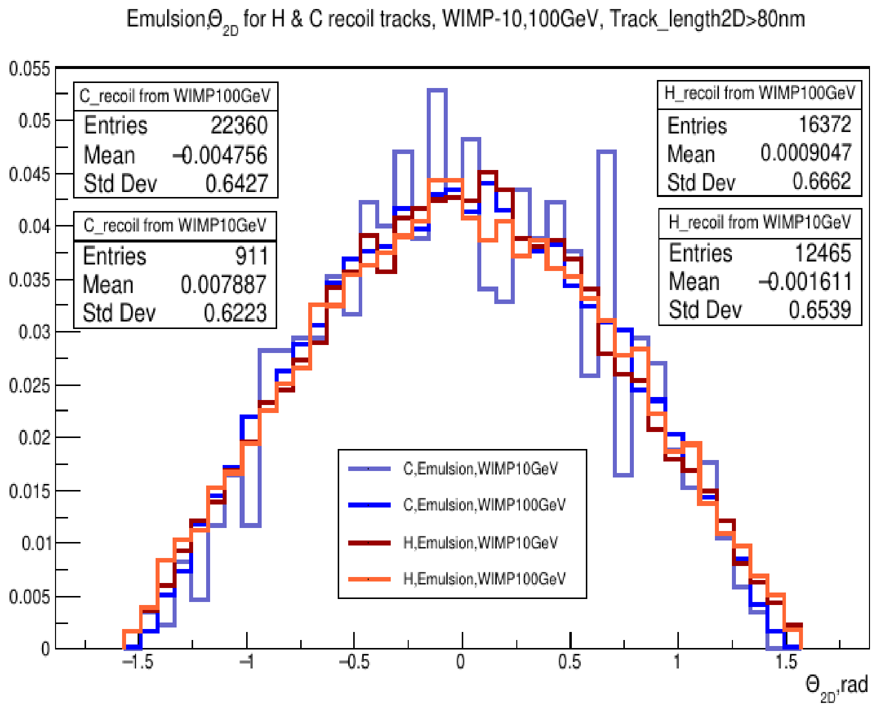


Figure 12. The current experimental parameter space for spin-independent WIMP-nucleon cross sections. Not all published results are shown. The space above the lines is excluded at a 90% confidence level. The two contours for DAMA interpret the observed annual modulation in terms of scattering of iodine (I) and sodium (Na), respectively [125]. The dashed line limiting the parameter space from below represents the "neutrino floor" [117] from the irreducible background from coherent neutrino-nucleus scattering (CNNS), see Sect. 3.4.

ArXiv:1903:03026v2

C and H recoil tracks in the emulsion from WIMP (10, 100 GeV/c^2) elastic scattering. Recoil track length distributions (left) and recoil tracks angular distributions (right) in the emulsion with density 3.44 g/cm^3.
0 rad corresponds to the constellation Cygnus direction.





Directional Observation of Cold Dark Matter Particles (WIMP) in Light Target Experiments Anna Anokhina 1,2,*, Vasilisa Gulyaeva 1, Emil Khalikov 2, Evgeny Kurochkin 1,2, Tatiana Roganova 2, Eduard Ursov 1,2,*

About ONE event (H & CNO RECOL TRACK) associated with the elastic scattering of WIMP in a 30 kg emulsion is expected.

Methodical track length threshold (minimal detectable track with determined direction) — 80 nm.

Target matter	Element	N_{WIMP} per day in 1 kg	Mass fraction, kg	N_{WIMP} per year	N_{ν} per year
emulsion	H	$7.15*10^{-7}$	1.11	$3*10^{-4}$	0.058
emulsion	C	$3.28*10^{-4}$	3.69	0.44	0.016
emulsion	N	$4.39*10^{-4}$	0.54	0.087	<0.003
emulsion	O	$5.61*10^{-4}$	2.76	0.56	<0.015

Cosmic Ray Boosted Dark Matter

Novel direct detection constraints on light dark matter

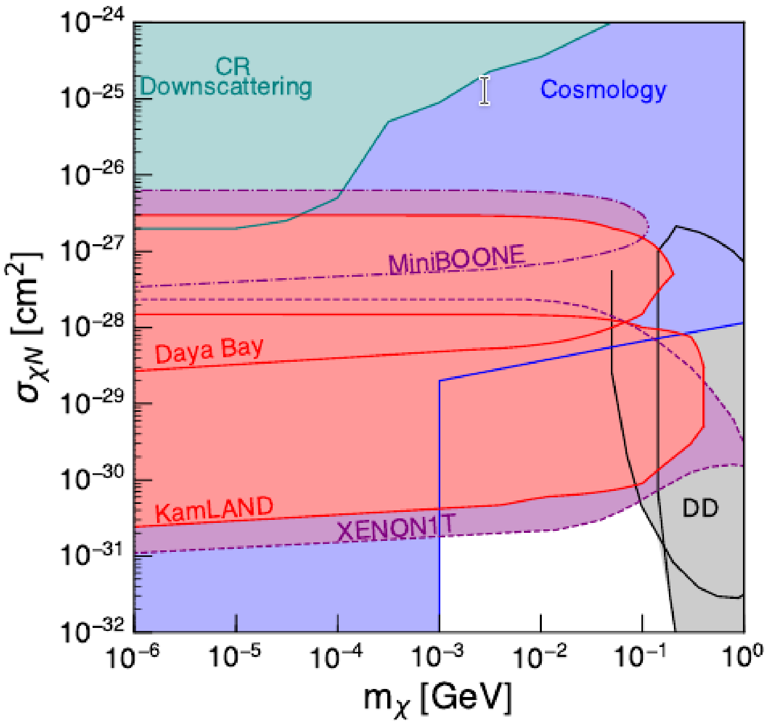
Torsten Bringmann[1] and Maxim Pospelov[2,3]

Reverse direct detection: Cosmic ray scattering with light dark matter

Christopher V. Cappiello, Kenny C. Y. Ng, and John F. Beacom
Phys. Rev. D **99**, 063004 – Published 8 March 2019

Production and attenuation of cosmic-ray boosted dark matter

Chen Xia[a], Yan-Hao Xu[a], and Yu-Feng Zhou[a,b,c]



How many recoil events can be expected in 10 kg of emulsion during 1 year of exposure?
Is it possible to expect an excess of the signal from the Galaxy Center direction?

Journal of Cosmology and Astroparticle Physics
An IOP and SISSA journal

Directional sensitivity of the NEWSdm experiment to cosmic ray boosted dark matter

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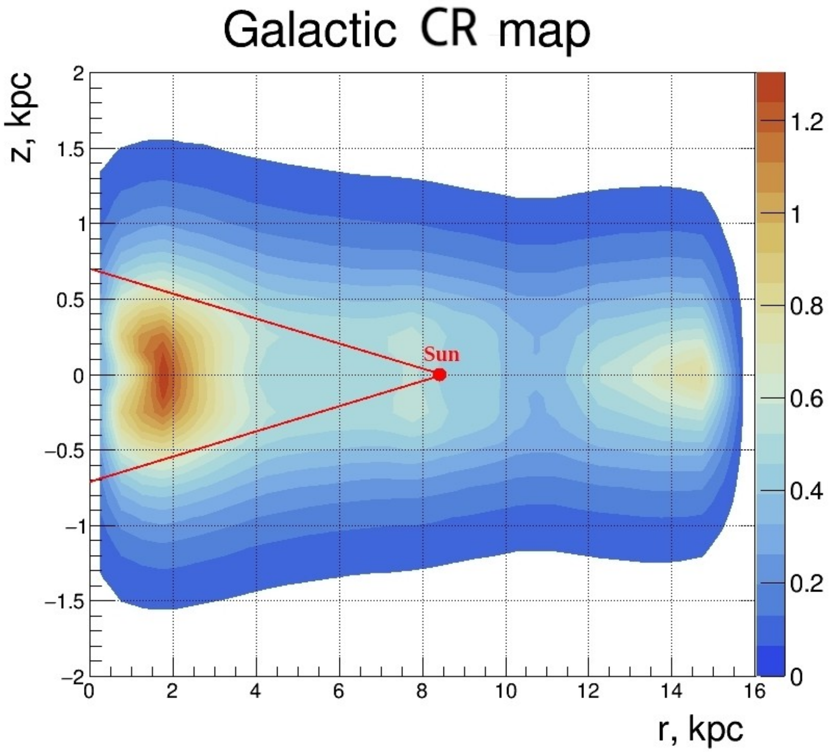
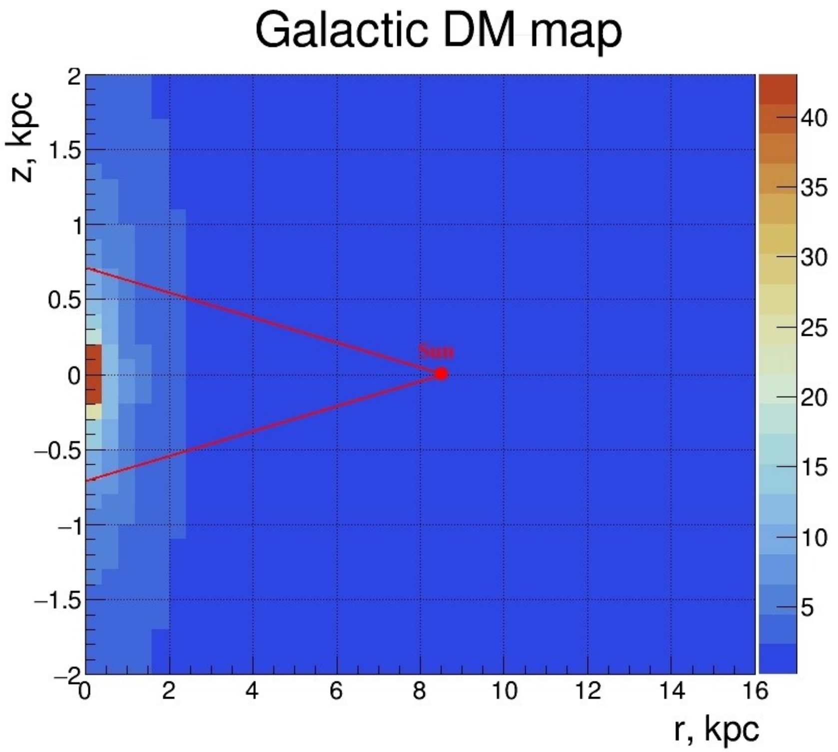
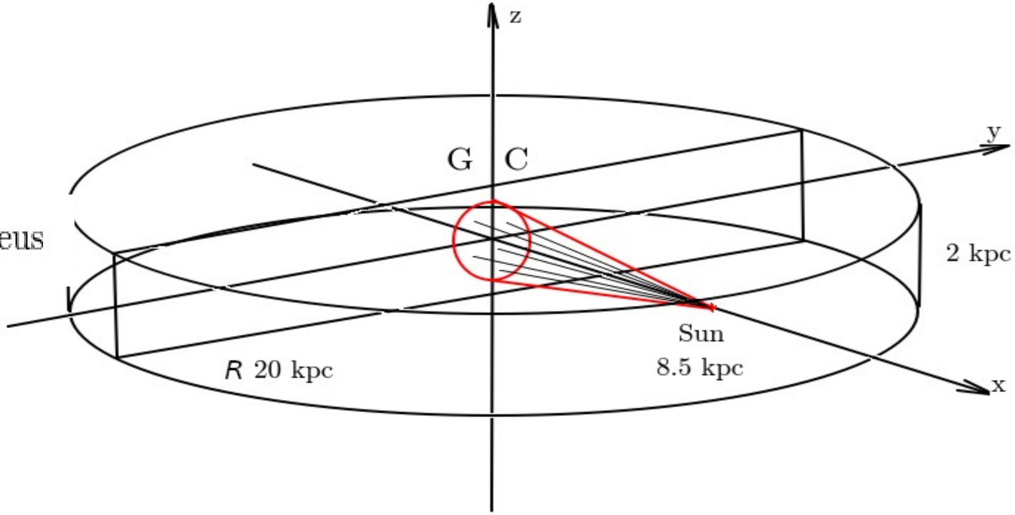
The model of dark matter particle accelerating by elastic interaction with cosmic rays.
The masses of DM particles — 1 keV/c^2 - 1GeV/c^2 (Light Dark Matter).





Cosmic rays — GALPROP data
Dark matter — Navarro-Frenk-White profile

$H^1, He^4, C^{12}, O^{16}, Ne^{20}, Mg^{24}, Si^{28}, S^{32}, Fe^{56}$ -95% of the flux from all CR nucleus



Cosmic Ray distributions: GALPROP v.57,
CR Galactic disk is 40 kpc in diameter
and 2 kpc thick, Nuclei: H1 to Ni64
DM profile: Navarro-Frenk-White (NFW)

$$\rho_\chi^{\rm nfw}(r) = \rho_s/[(r/r_s)(1 + r/r_s)^2] \text{ with } r_s = 20 \text{ kpc and}$$

$$\rho_s = 0.35 \text{ GeV cm}^{-3}$$

$$\frac{d\Phi_\chi}{dT_\chi} = \int_{\rm l.o.s} d\ell \frac{\rho_\chi(\boldsymbol{r})}{m_\chi} \int_{T_i^{\rm min}} dT_i \frac{d\sigma_{\chi i}}{dT_\chi} \frac{d\Phi_i(\boldsymbol{r})}{dT_i}$$

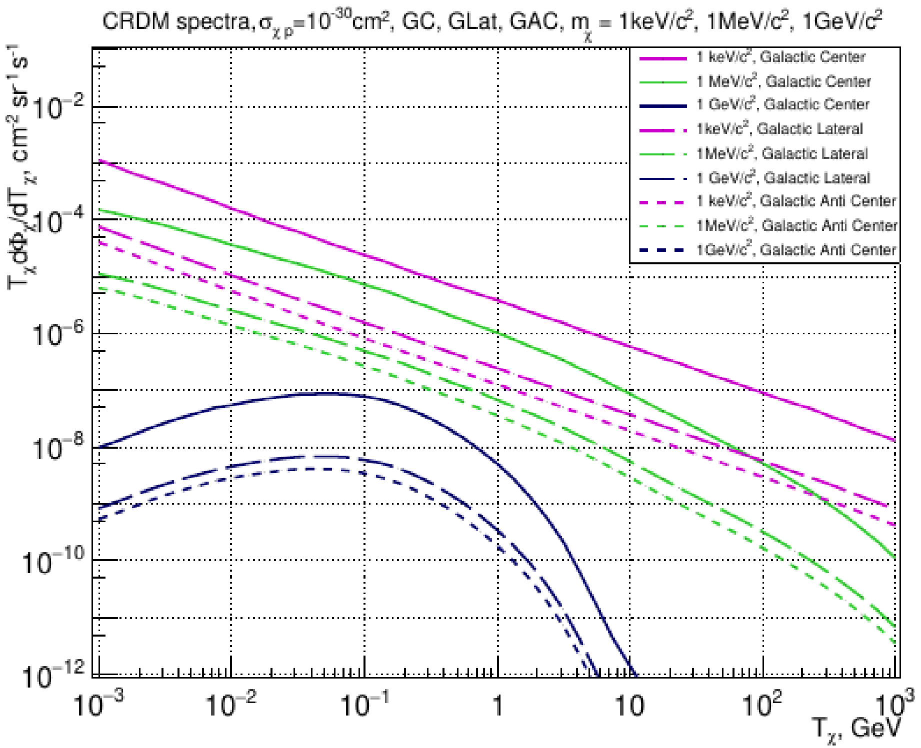
Only elastic collisions, form factor accounted for

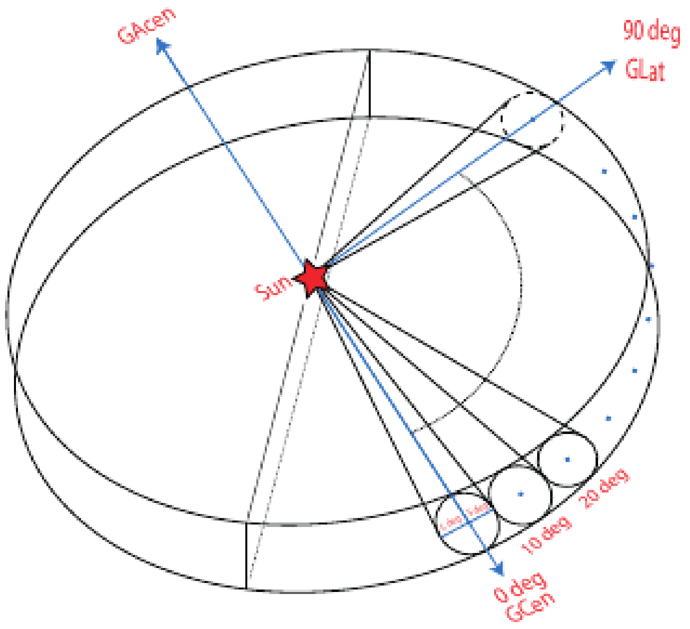
$$\frac{d\sigma_{\chi i}}{dT_\chi} = \frac{F_i^2(q^2) A_i^2}{T_\chi^{\rm max}(T_i)} \frac{\mu_{\chi i}^2}{\mu_{\chi p}^2} \sigma_{\chi p}$$

$$\sigma_{\chi p} = 10^{-30}, 10^{-29}, 10^{-28} \text{ cm}^2$$

CRDM (cosmic ray boosted dark matter) in the directions
GC (Galactic Center), Glat (Lateral direction), GAC (Galactic Anti Center)

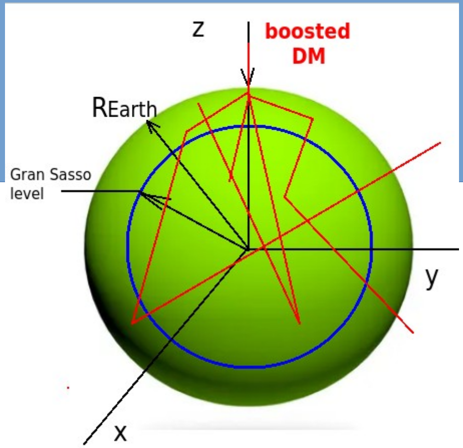
$\sigma_{\chi p} = 10^{-30}, 10^{-29}, 10^{-28}\ \mathrm{cm}^2$

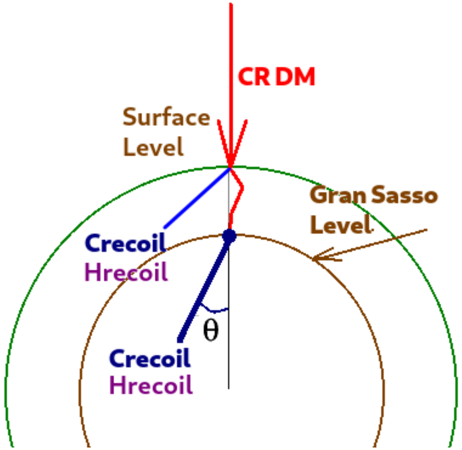


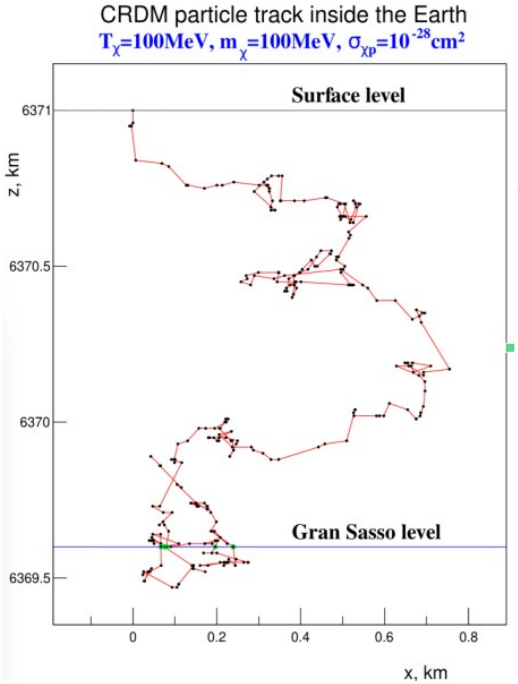


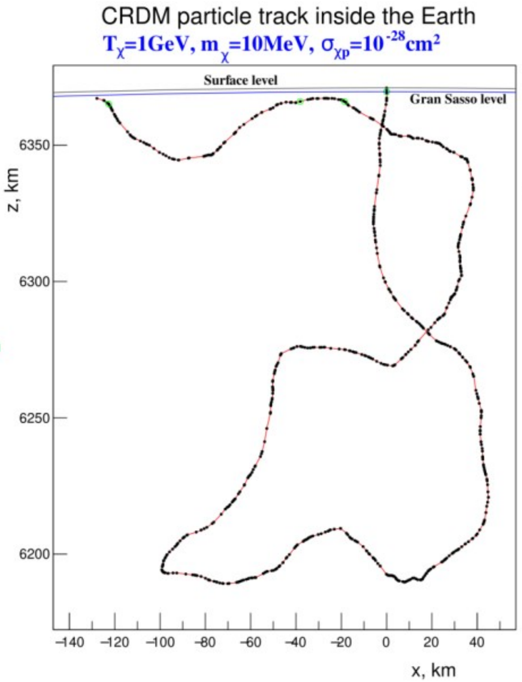
Three DM masses (1 keV, 1 MeV, 1 GeV) are considered as an example.

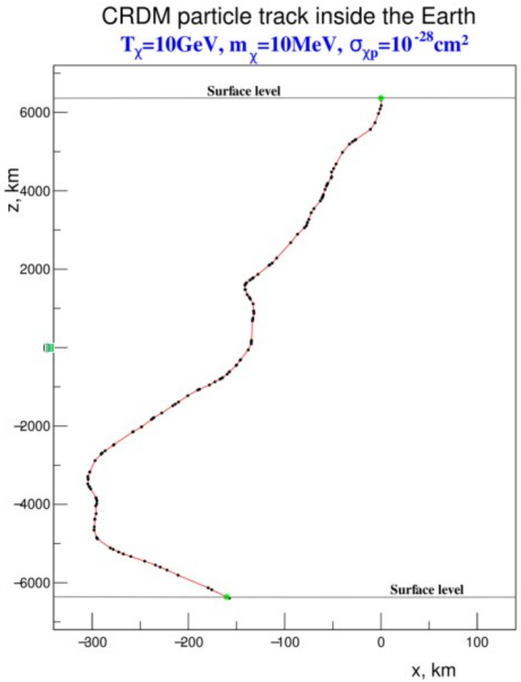
DM attenuation effect in the Earth
Surface level — Underground Lab level (GranSasso)







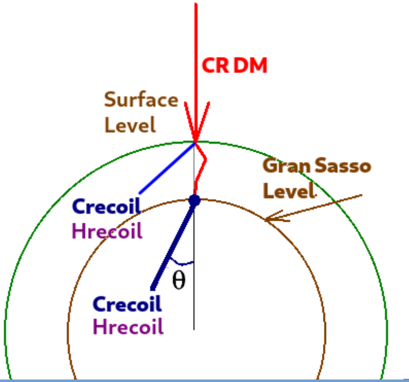


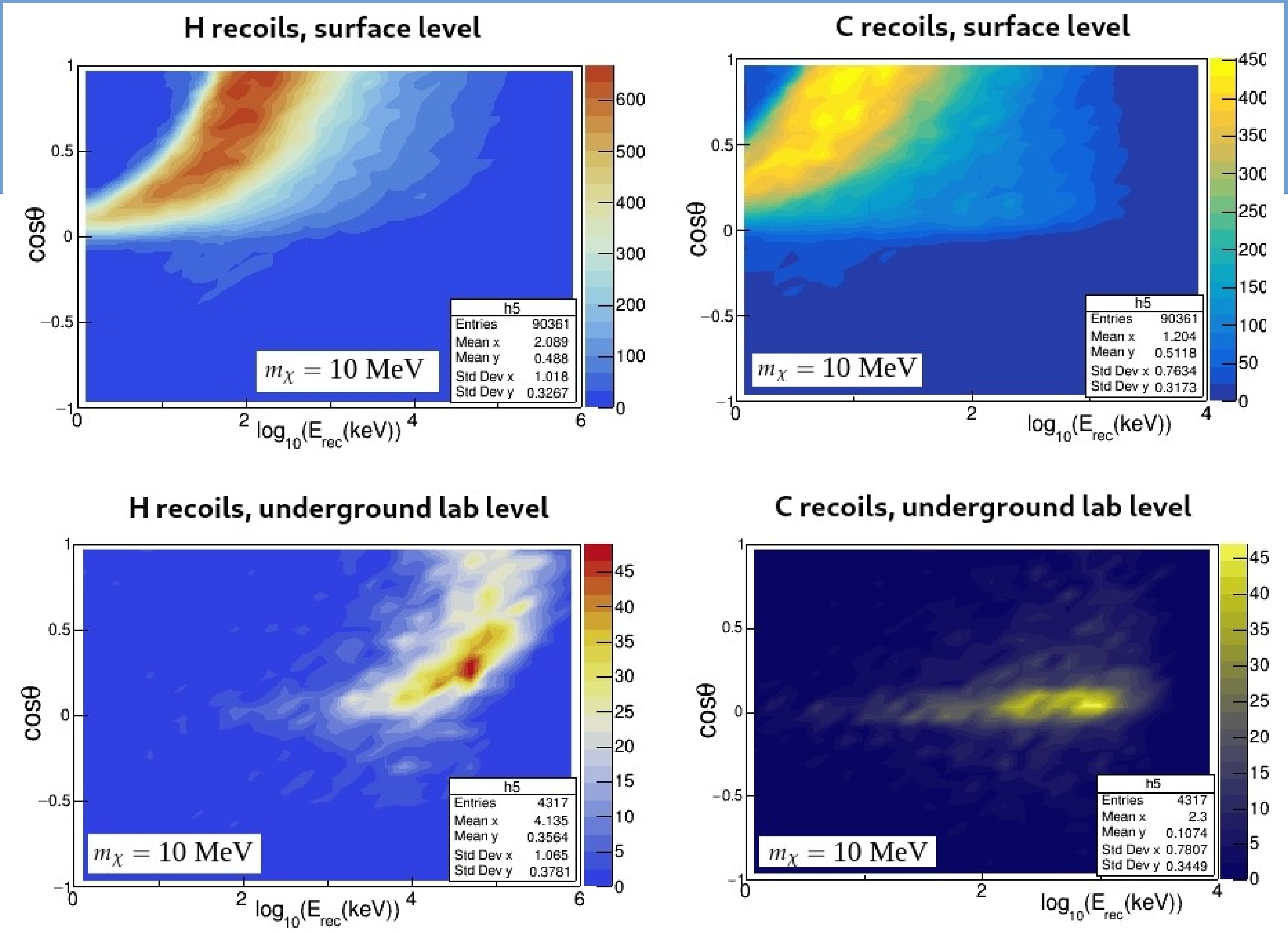


H and C recoils energy and cos θ distributions.

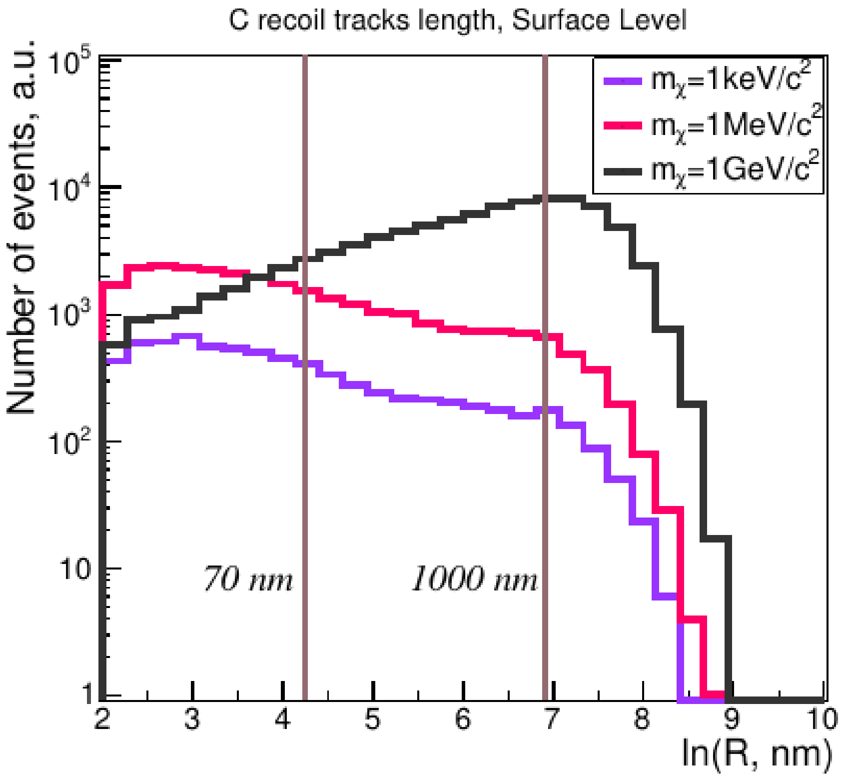
DM masses:
1, 10, 100 keV/c^2,
1, 10, 100 MeV/c^2,
1GeV/^2

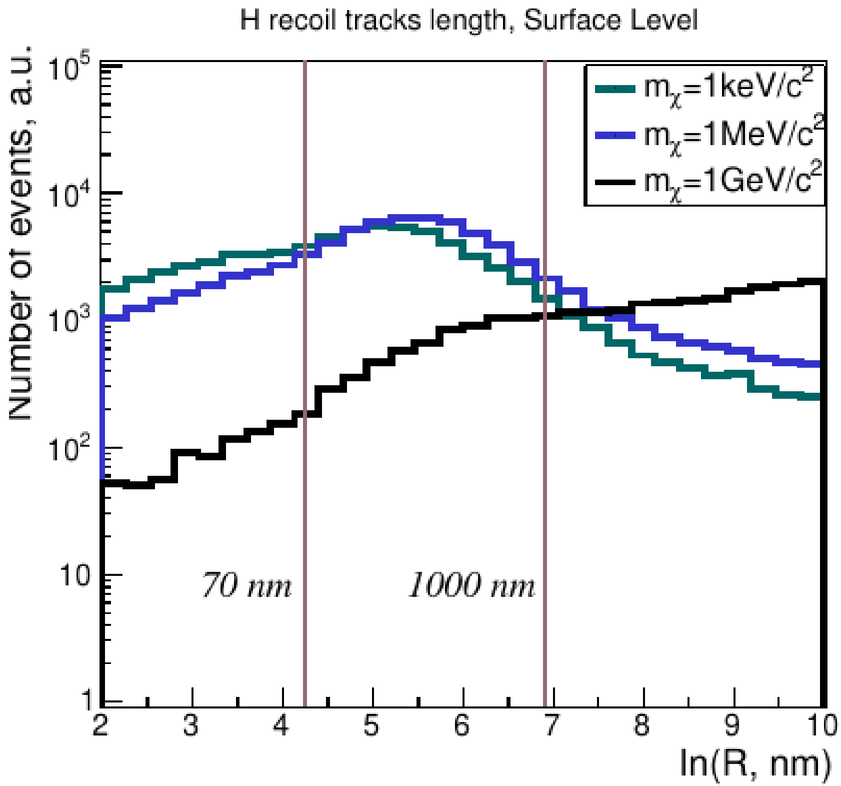
at the surface level
and
at the underground
Lab level





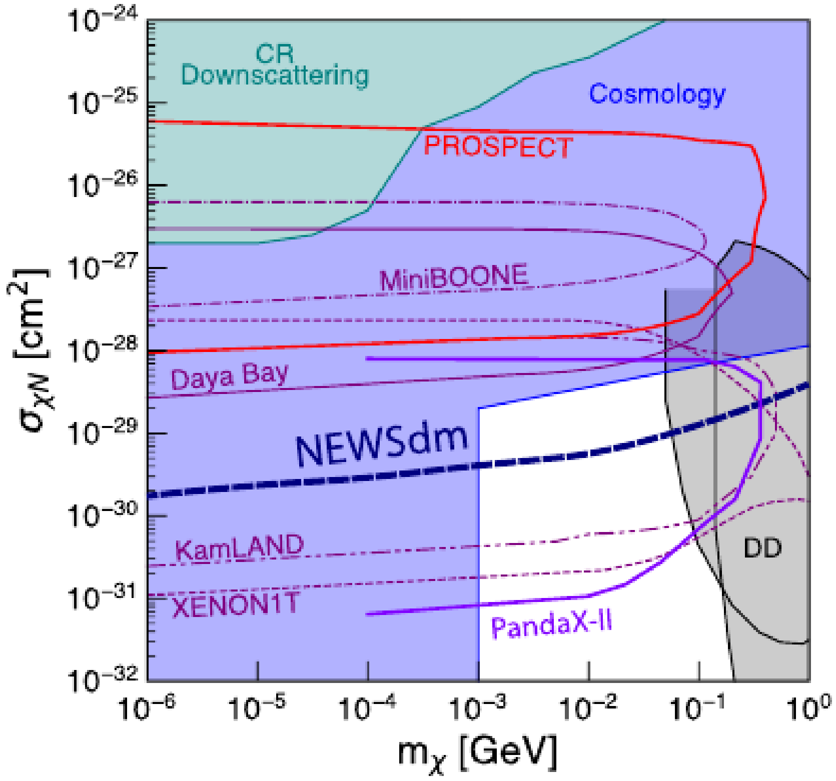
GEANT4 modeling: C and H recoil track length distributions.
Surface level. Vertical lines indicate two options for the threshold value for the track length.





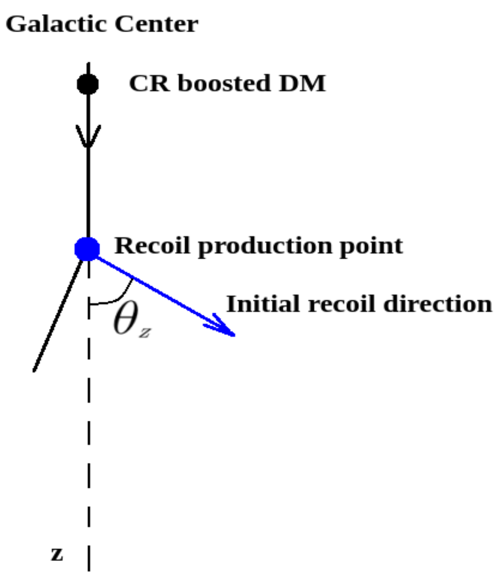
Sensitivity NEWSdm detector for CRDM

Sensitivity curve of the NEWSdm detector with 10 kg nuclear emulsion for 1 year of exposure at the surface level for CRDM
and limits from cosmology and other experiments.
The boundary go through the dots corresponding to three H and CNO recoil events with track length longer than 70 nm for zero background.

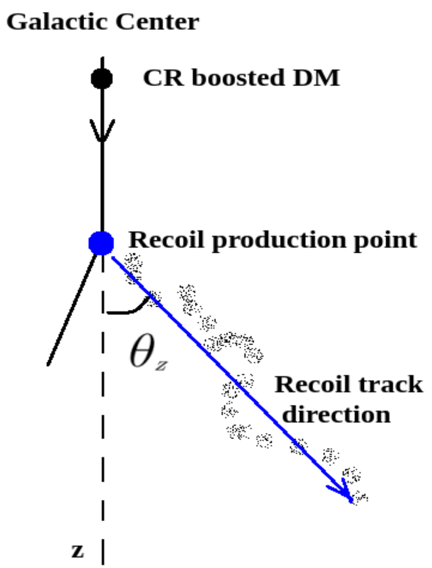


Are the tracks of recoil nuclei directed to the source of dark matter particles?

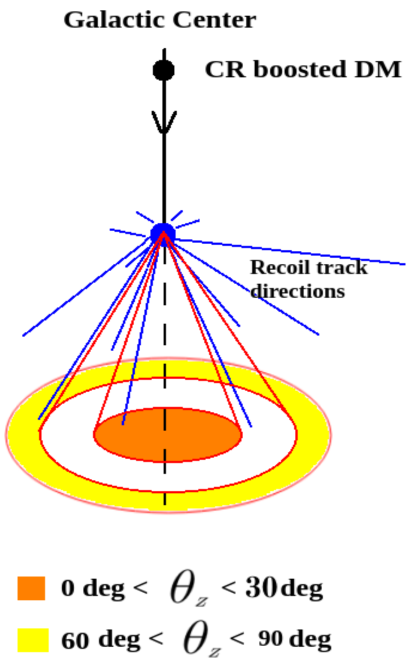
Cross section $\sigma_{\chi p}=10^{-28}$ cm^2 is considered as an example, the final result is made for $\sigma=10^{-28}, 10^{-29}, 10^{-30}$ cm^2



1. H and C recoil production in the elastic Interaction with boosted DM



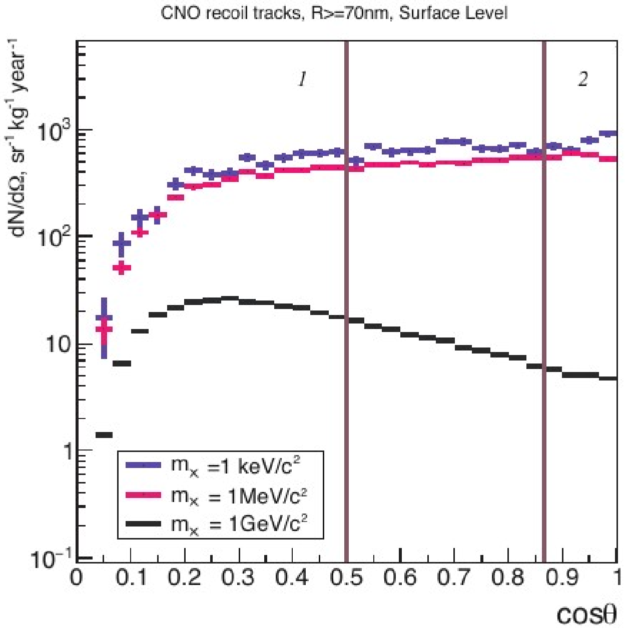
2. H and C recoil tracking with GEANT4 in the emulsion

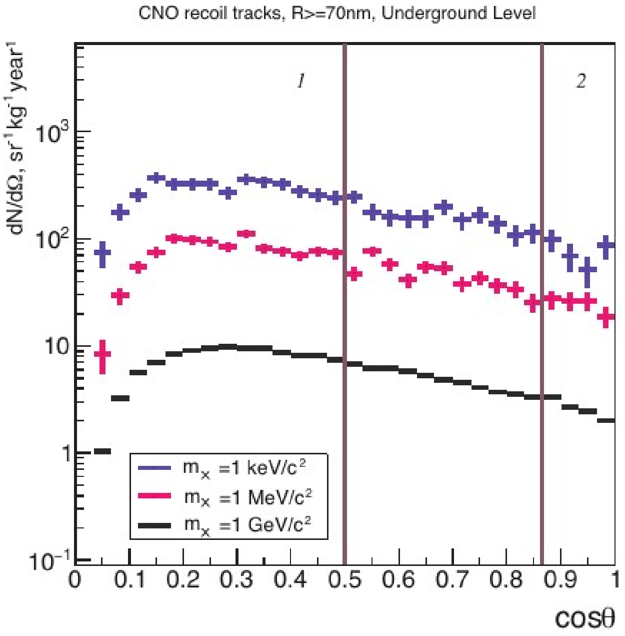


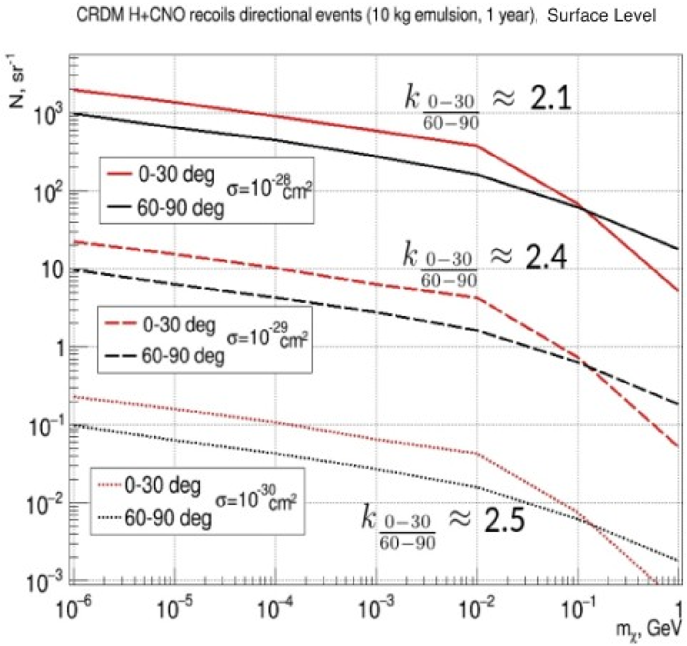
3. As an example the number of events in two angle ranges was compared.

Angular distributions of recoil nuclei tracks (CNO) on the Earth's surface and at the level of the GranSasso underground laboratory.

Conclusion: it makes sense to look for a signal at the Galaxy Center direction at the Surface Level and for Dark Matter particle with masses 1 keV/c^2 - 10 MeV/c^2.







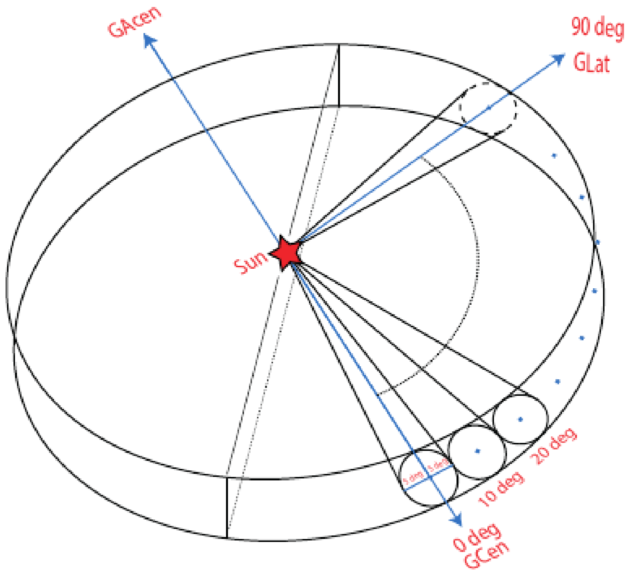
The directionality effect:

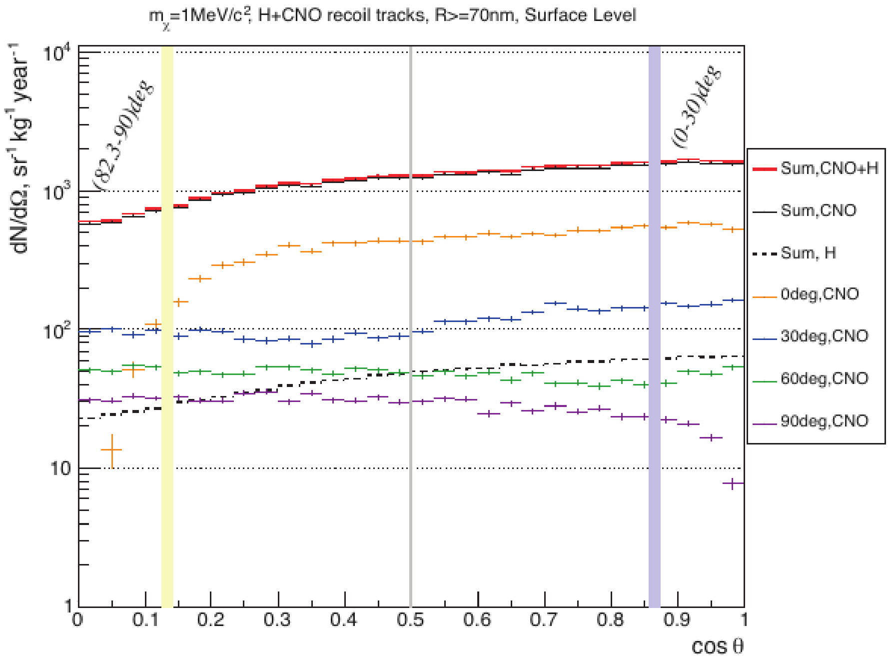
3.5 times more tracks of CNO and H recoil nuclei in the emulsion can be expected from DM particles with masses

from 1 keV/c^2 to 1 MeV/c^2 coming from the Center of the Galaxy than from those coming from the perpendicular direction.

Table 1.

DM mass	N_{0-3}	N_{26-29}	$\frac{N_{26-29}}{N_{0-3}}$
$1\ keV/c^2$	2319.8	8158.5	3.5
$1\ MeV/c^2$	1820.2	6531.2	3.6
$1\ GeV/c^2$	100.9	102.4	1.0





Conclusions

We have reported a study on the nuclear recoils induced by CRDM interactions with the nuclei of the NIT emulsion films for a module of the NEWSdm detector.

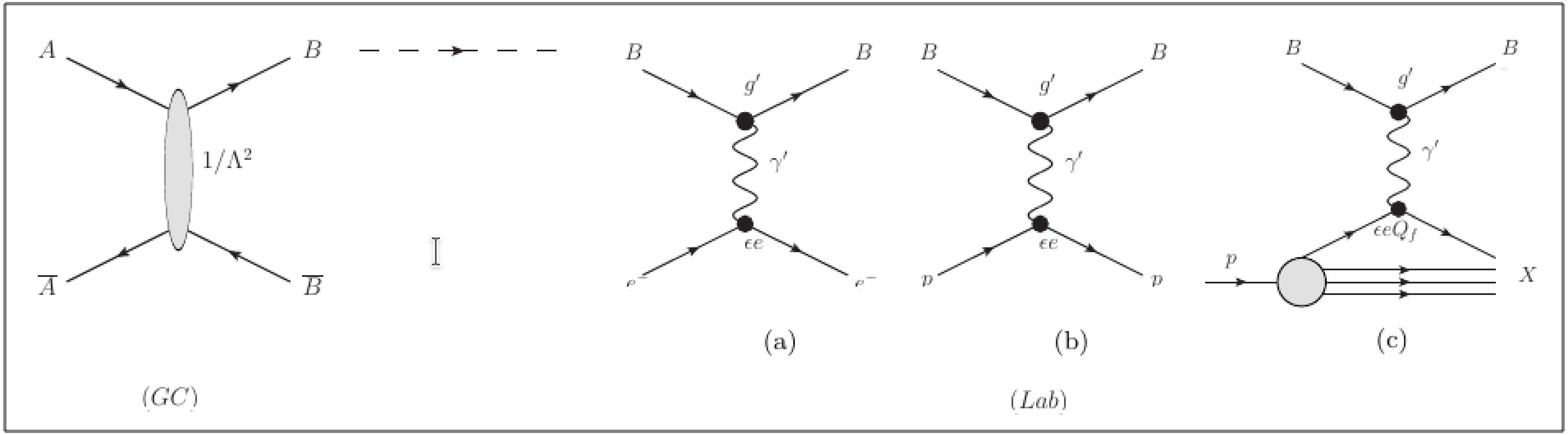
At the surface laboratory, one can expect a factor of 3.5 in the ratio between the number of recoil track events detected in the direction of the Galactic Center when compared to the orthogonal direction.

A module of the NEWSdm apparatus consisting of 10 kg emulsion detector exposed for one year at the surface laboratory on an equatorial telescope can independently explore the existence of cosmic ray boosted DM particles in the mass range from 1 keV/c^2 to 1 GeV/c^2 for cross-section values down to 10^{−30} cm^2.

Our next step - NEWSdm detector for Two Component Dark Matter

(Left) Production of boosted DM_B particles through DM_A annihilation in the galactic center.

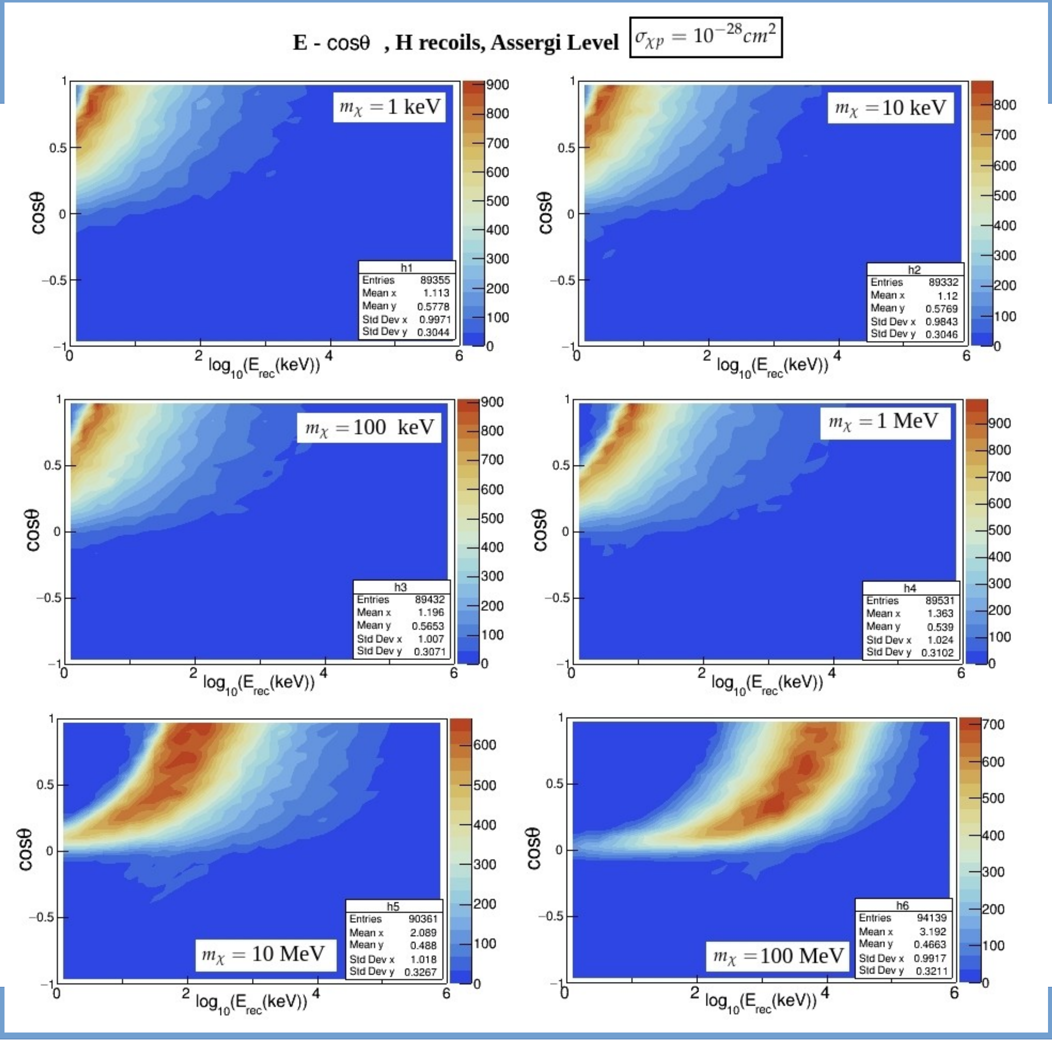
(Right) Scattering of DM_B in the target (emulsion)

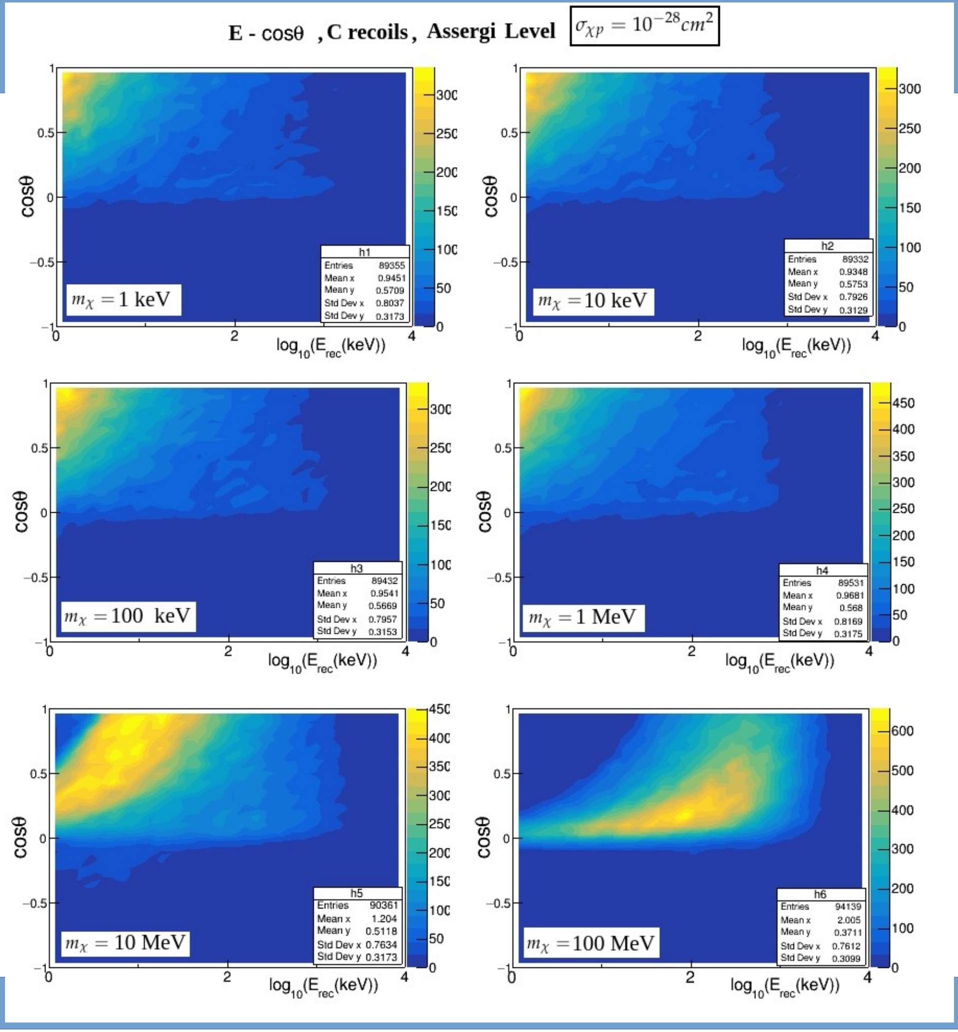


Thank you for your attention !

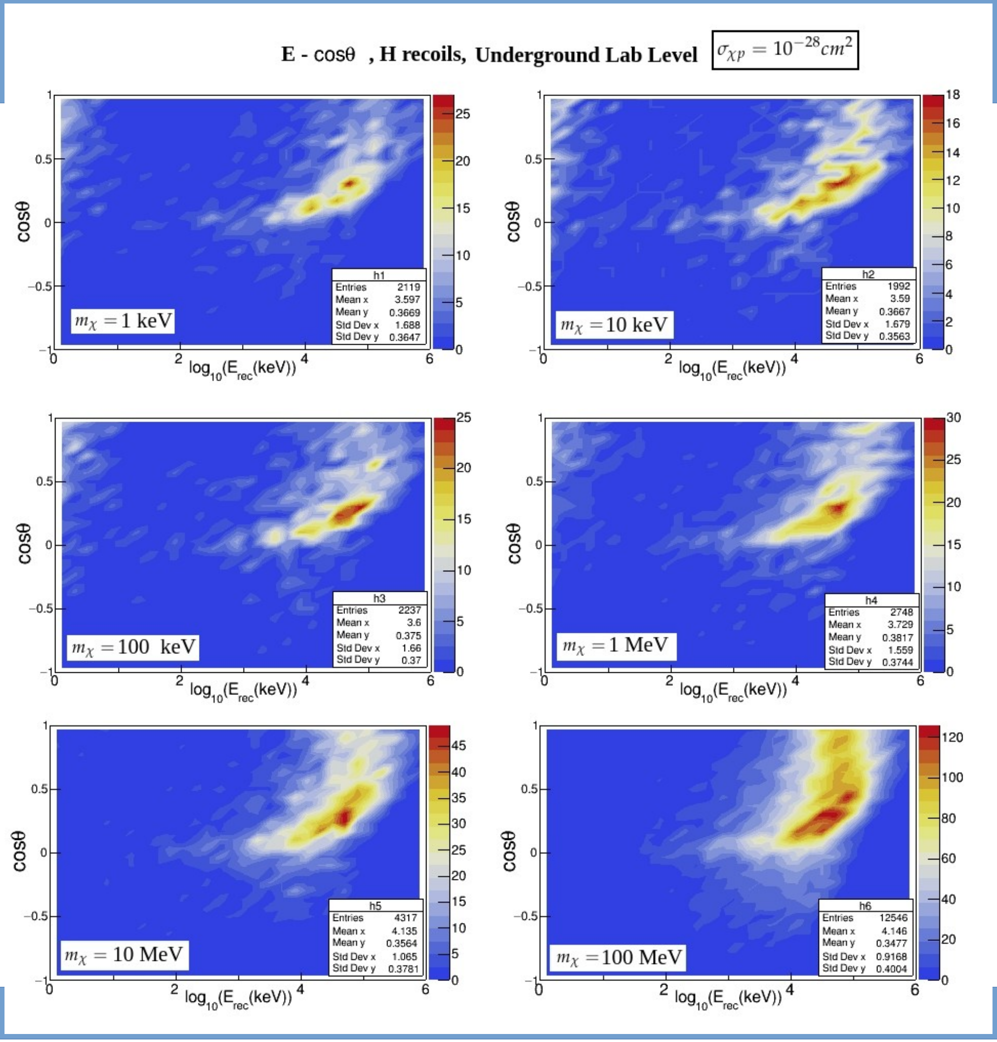
H and C recoils energy and cosθ distributions.

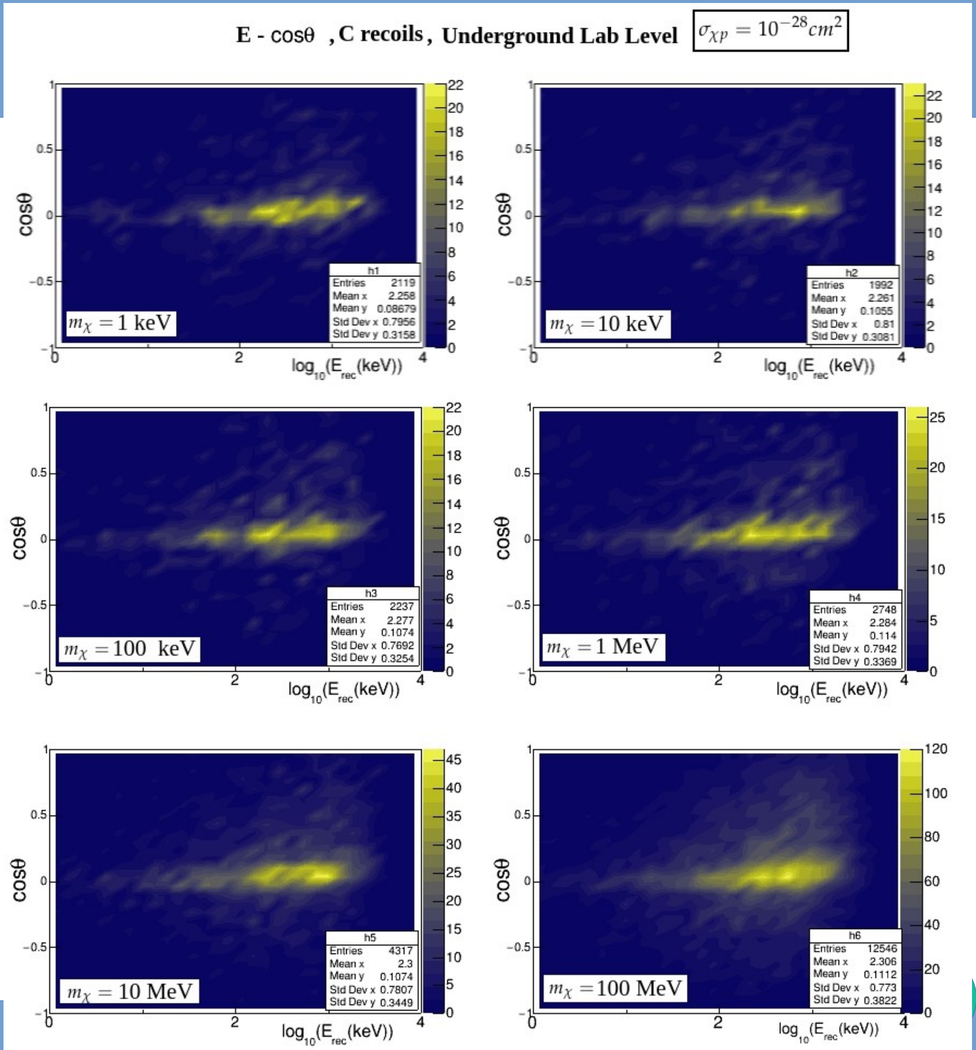
DM masses: 1, 10, 100 keV/c^2, 1, 10, 100 MeV/c^2, 1GeV/^2 at the SURFACE level.



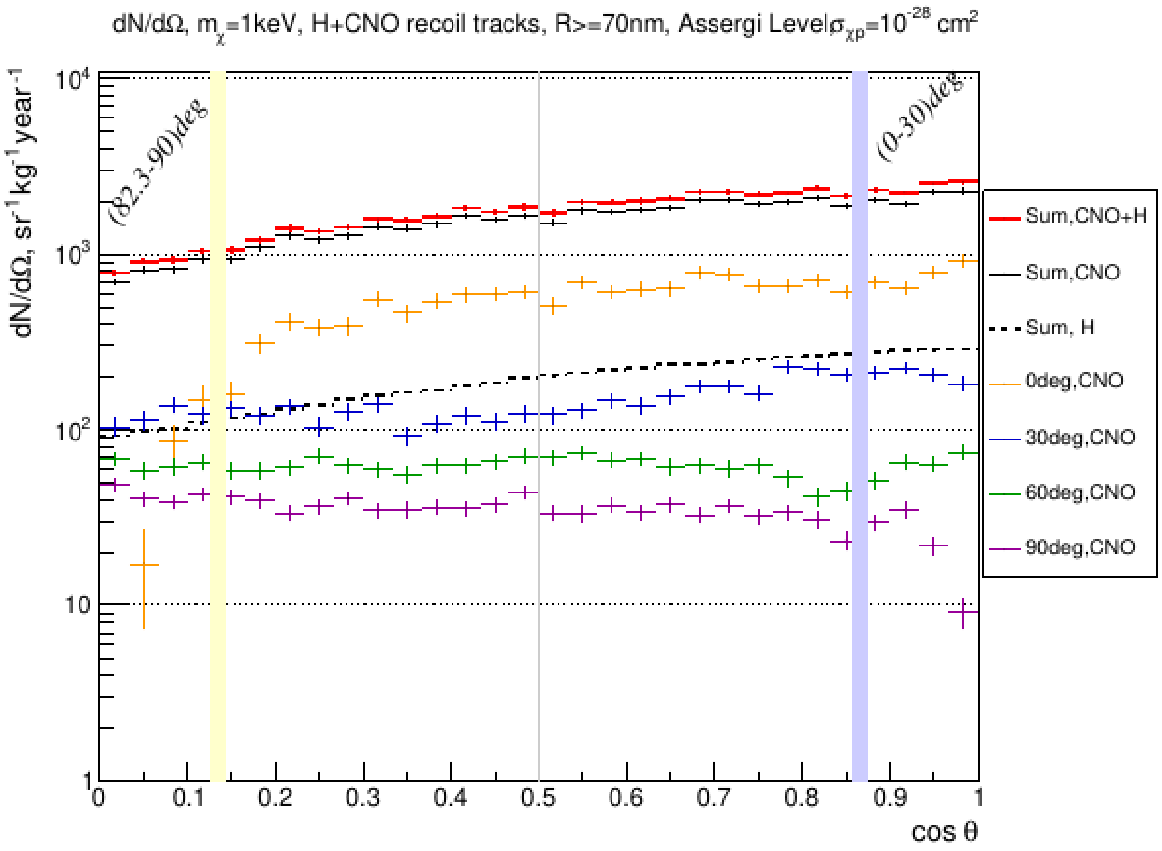


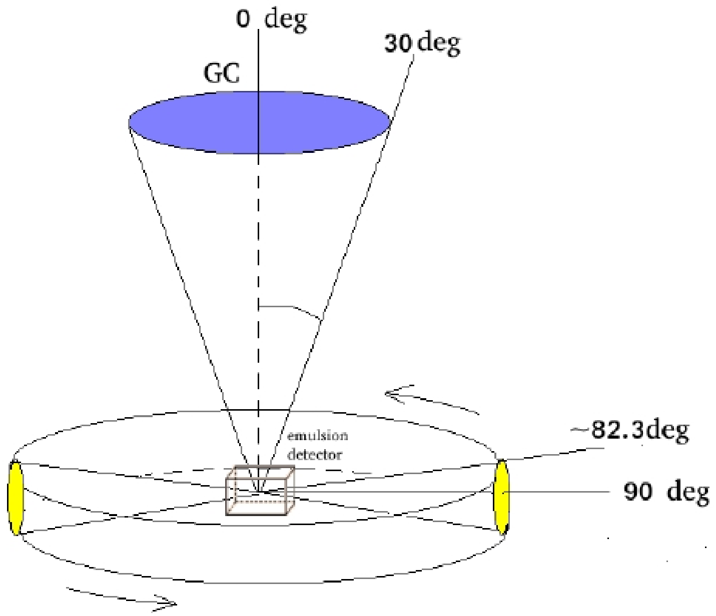
H and C recoils energy and cosθ distributions.
DM masses: 1, 10, 100 keV/c^2, 1, 10, 100 MeV/c^2, 1GeV/^2 at the GranSasso underground lab level.





Сравнение количества треков ядер отдачи по направению на Центр Галактики и в перпендикулярном направлении (в плоскости Галактики).





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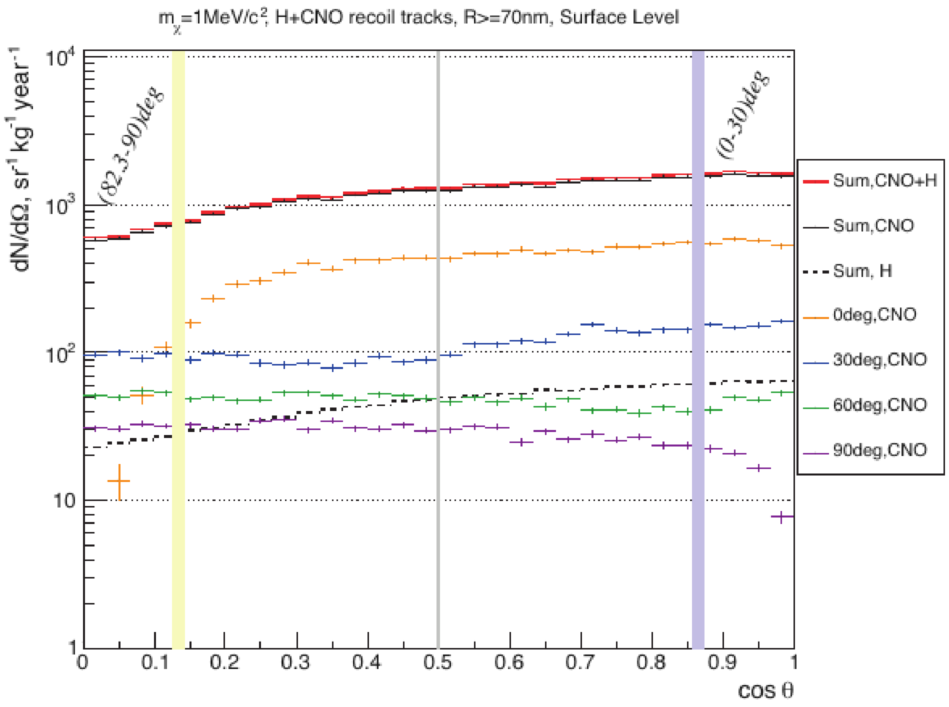
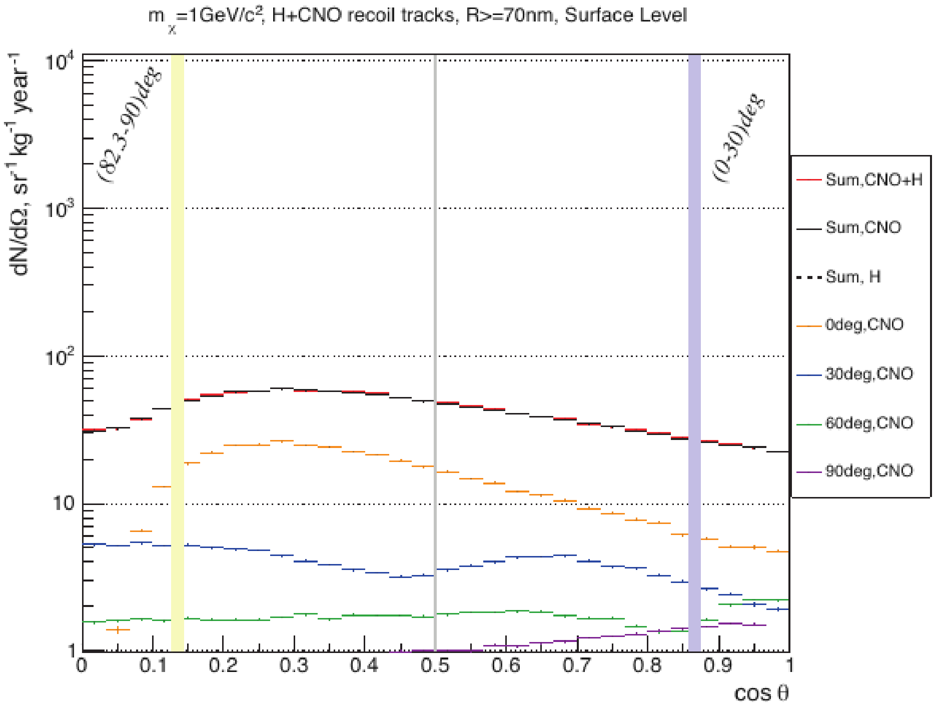




- Была рассмотрена модель ТЕМНОЙ МАТЕРИИ, взаимодействующей с частицами СМ посредством массивного темного фотона(медиатора), кинетически смешивающегося с γ/Z_0 , удовлетворяющая диапазону сечений взаимодействия частицы темной материи с баритонным веществом
- Диапазон сечений: $\sigma_{\chi p} = 10^{-30}$ до $\sigma_{\chi p} = 10^{-28}$
- Параметры для подбора следующие:
- $\sigma^V_{N\to\chi N}(\epsilon, \alpha', m_V, m_{\chi},)$, где эпсилон - константа кинетического смешивания
- Альфа - константа взаимодействия с ТМ

$$\mathcal{L} = \mathcal{L}_\chi - \frac{1}{4}V_{\mu\nu}V^{\mu\nu} + \frac{1}{2}m_V^2 V_\mu V^\mu - \frac{\epsilon}{2}V^{\mu\nu}F_{\mu\nu} + q_B g' V_\mu J_B^\mu + \cdots$$

$$\mathcal{L}_\chi = \begin{cases} i\bar{\chi}\not{D}\chi - m_\chi\bar{\chi}\chi, & \text{(Dirac fermion DM)} \\ |D_\mu\chi|^2 - m_\chi^2|\chi|^2, & \text{(Complex scalar DM)} \end{cases}$$

$$\frac{d\sigma^V_{N\to\chi N}}{dE_\chi} = \frac{\alpha'\kappa^2}{\alpha} \times \frac{4\pi\alpha^2[F^2_{1,N}(Q^2)A(E,E_\chi) - \frac{1}{4}F^2_{2,N}(Q^2)B(E,E_\chi)]}{(m_V^2 + 2m_N(E-E_\chi))^2(E^2 - m_\chi^2)},$$

где E и E_χ - энергии ТМ до и после взаимодействия

$$Q^2 = 2m_N(E - E_\chi) \quad F_{1,N} = q_N/(1+Q^2/m_N^2)^2$$

$$F_{2,N} = \kappa_N/(1+Q^2/m_N^2)^2$$

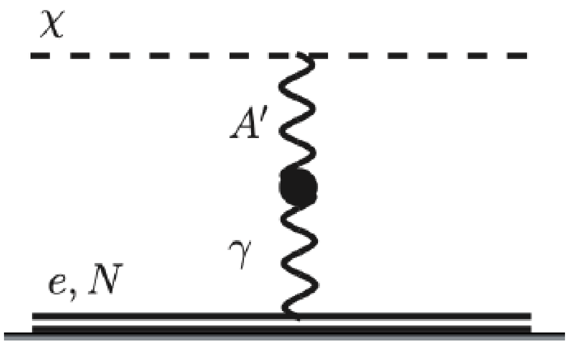
$$q_p = 1, q_n = 0, \kappa_p = 1{,}79, \kappa_n = -1{,}9.$$

Light dark matter in neutrino beams: production modelling and scattering signatures at MiniBooNE, T2K and SHiP

Patrick deNiverville,[1] Chien-Yi Chen,[1,2] Maxim Pospelov,[1,2] and Adam Ritz[1]

$$A(E,E_\chi) = 2m_N E E_\chi - m_\chi^2(E - E_\chi)],$$

$$B(E,E_\chi) = (E_\chi - E)[(E_\chi + E)^2 + 2m_N(E_\chi - E) - 4m_\chi^2]$$



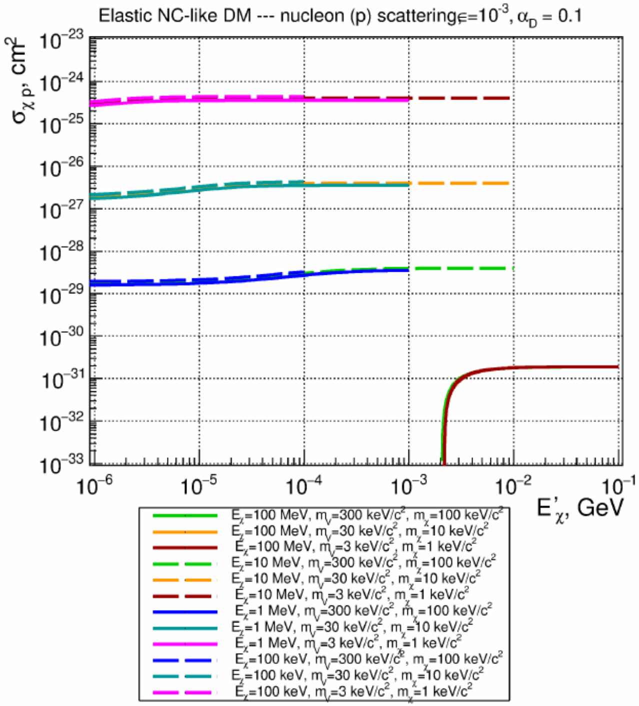


Рис. 6.3: Полное сечение упругого взаимодействия $\sigma_{\chi p}$ в зависимости кинетической энергии рассеянной частицы темной материи E'. Для масс m, 1, 10, 100 кэВ/с^2 и энергий до рассеяния $E_\chi = 0.1$, 1, 10 и 100 МэВ.

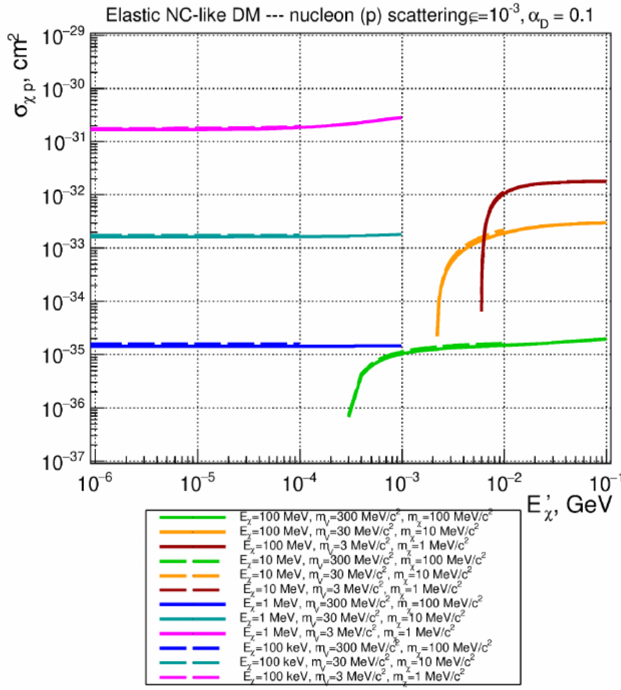


Рис. 6.4: Полное сечение упругого взаимодействия $\sigma_{\chi p}$ в зависимости от кинетической энергии рассеянной частицы темной материи E'. Для масс m_χ = 1, 10, 100 МэВ/с^2 и энергий до рассеяния $E_\chi = 0.1$, 1., 10. и 100. МэВ.